



BPS

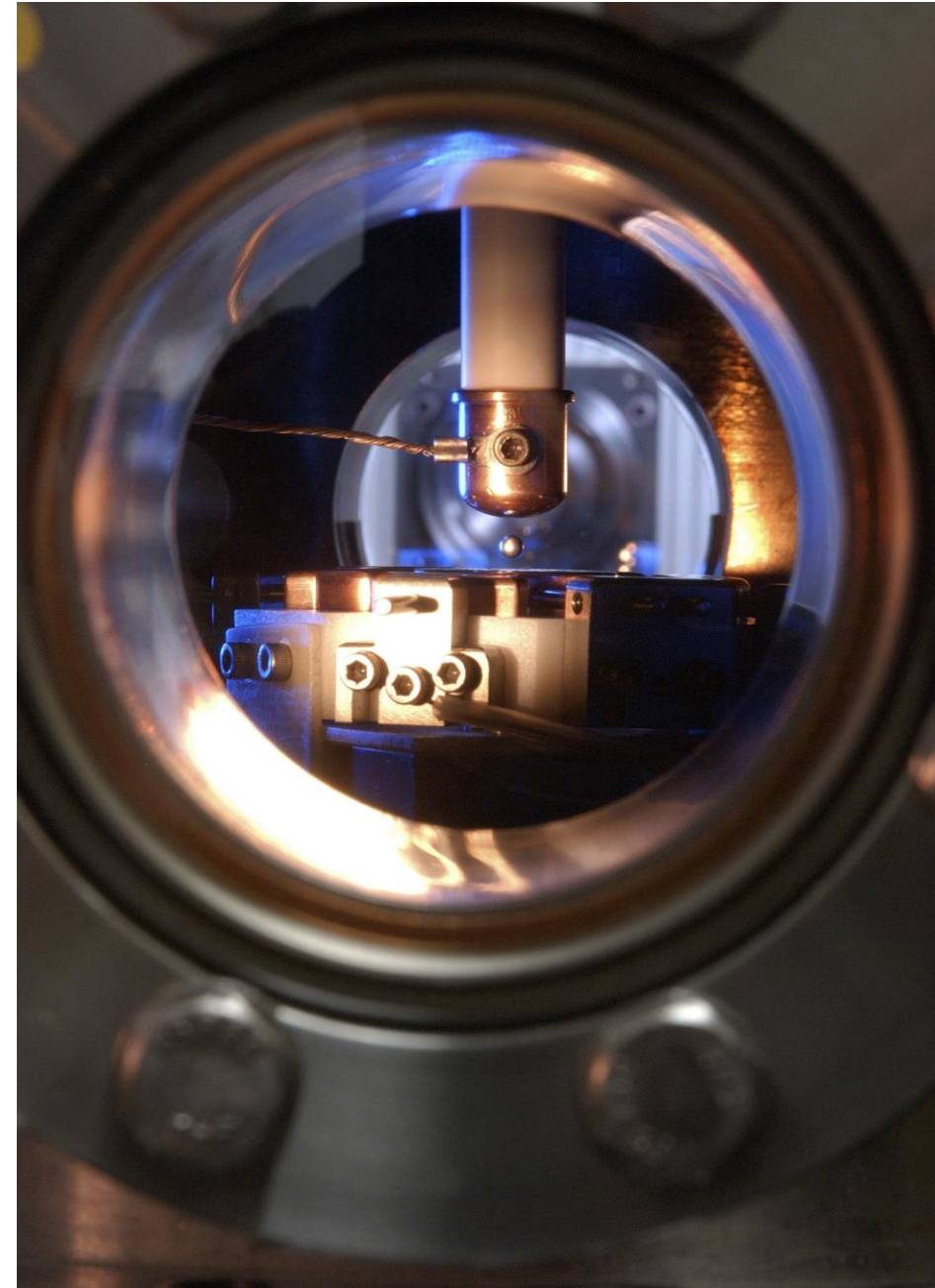
BIOLOGICAL AND
PHYSICAL SCIENCES

Effects of Oxygen on the Surface Tension of Liquid Inconel 718

Michael P. SanSoucie
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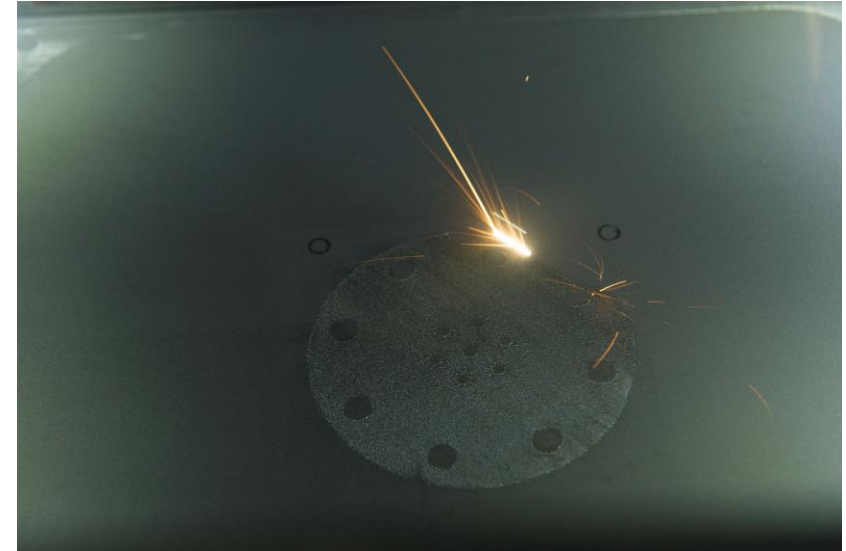
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Need for Thermophysical Properties

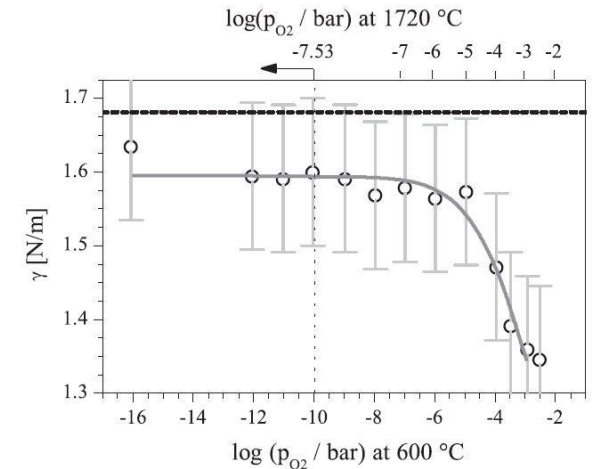
- **Need high quality thermophysical properties of high-temperature materials.**
- **These properties are critical for developing accurate models with predictive capability**
 - Welding
 - Additive Manufacturing
- **Measurements will improve manufacturing of propulsion components, leading to higher performance and higher reliability.**



Selective laser melting of a part.
Image courtesy of NASA.

Need for Oxygen Control

- **Surface tension of molten metals is affected by even a small amount of adsorption of oxygen**
- **Oxidation may have an impact of 10-30% on surface tension measurements¹.**
- **Typically causes a decrease in surface tension**
- **Oxidation can occur at very low pO_2**
 - Has been observed in the MSFC ESL as low as $\sim 10^{-25}$ bar pO_2



The surface tension γ of 99.999% Ni as a function of pO_2 measured by Schulz et. al.²

References:

1. Ozawa, S., et. al., Influence of oxygen partial pressure on surface tension and its temperature coefficient of molten iron, Journal of Applied Physics, 2011, 109.
2. Schulz, M., et. al., Oxygen partial pressure control for microgravity experiments, Solid State Ionics, 225, 2012, p. 332-336.

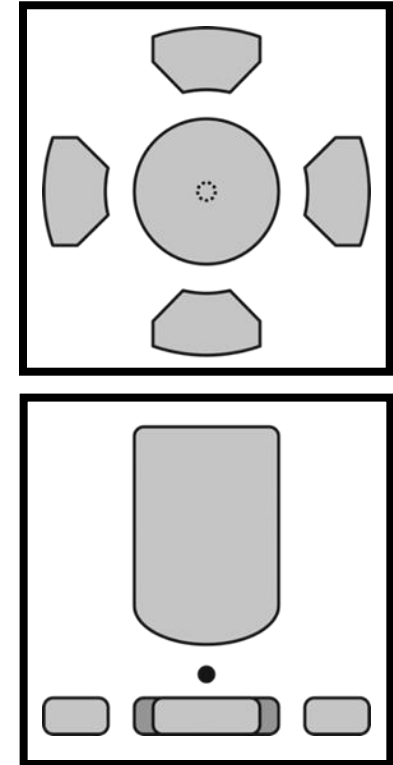
Supports Microgravity

- **This system supports microgravity principal investigators:**
 - A similar oxygen control system is planned for the European Space Agency (ESA) International Space Station Electromagnetic Levitator (ISS – EML).
 - Japan Aerospace Exploration Agency (JAXA) Electrostatic Levitation Furnace (ELF) on the ISS



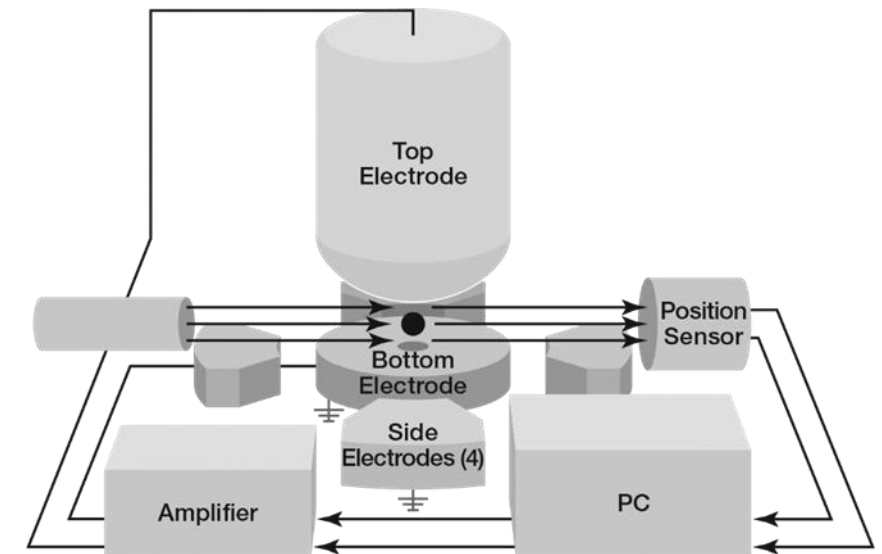
Electrostatic Levitation

- **Electrostatic levitation (ESL)**
 - uses Coulomb forces acting on an electrically charged sample
- **Electrostatic field**
 - generated by six electrodes
 - positioned in pairs along three mutually orthogonal lines.
- **Three of the six electrodes are grounded**
 - other three electrodes are each connected to individual high voltage amplifiers.
- **Provides an unobstructed view of the levitated sample**



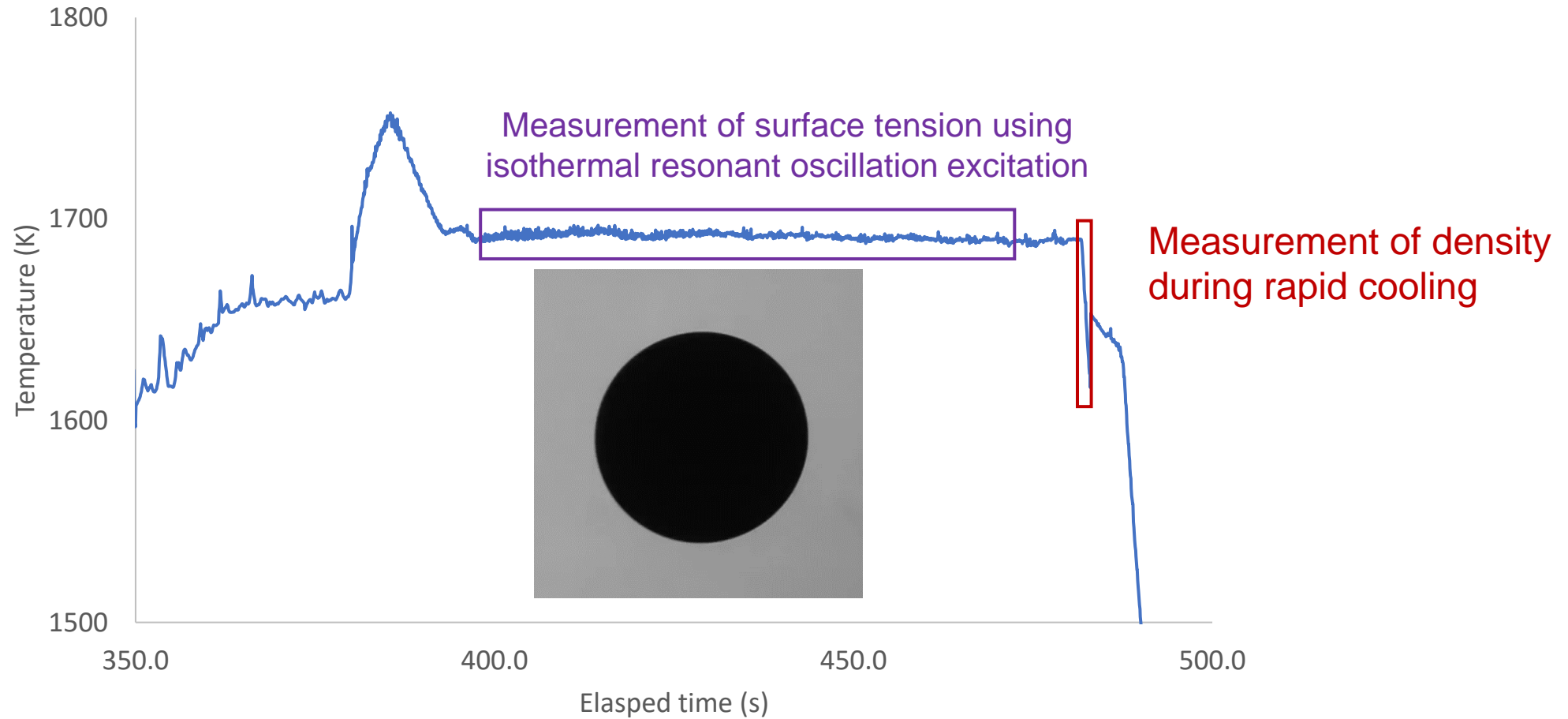
Electrostatic Levitation

- **An electrostatic field does not have a three-dimensional potential minimum**
 - Active control is required
- **Sample position measured**
 - two dual-axis position sensitive detectors (PSD)
 - two collimated light sources, e.g. LED lights.
- **Heating by laser**
 - decouples the heating from the position control.

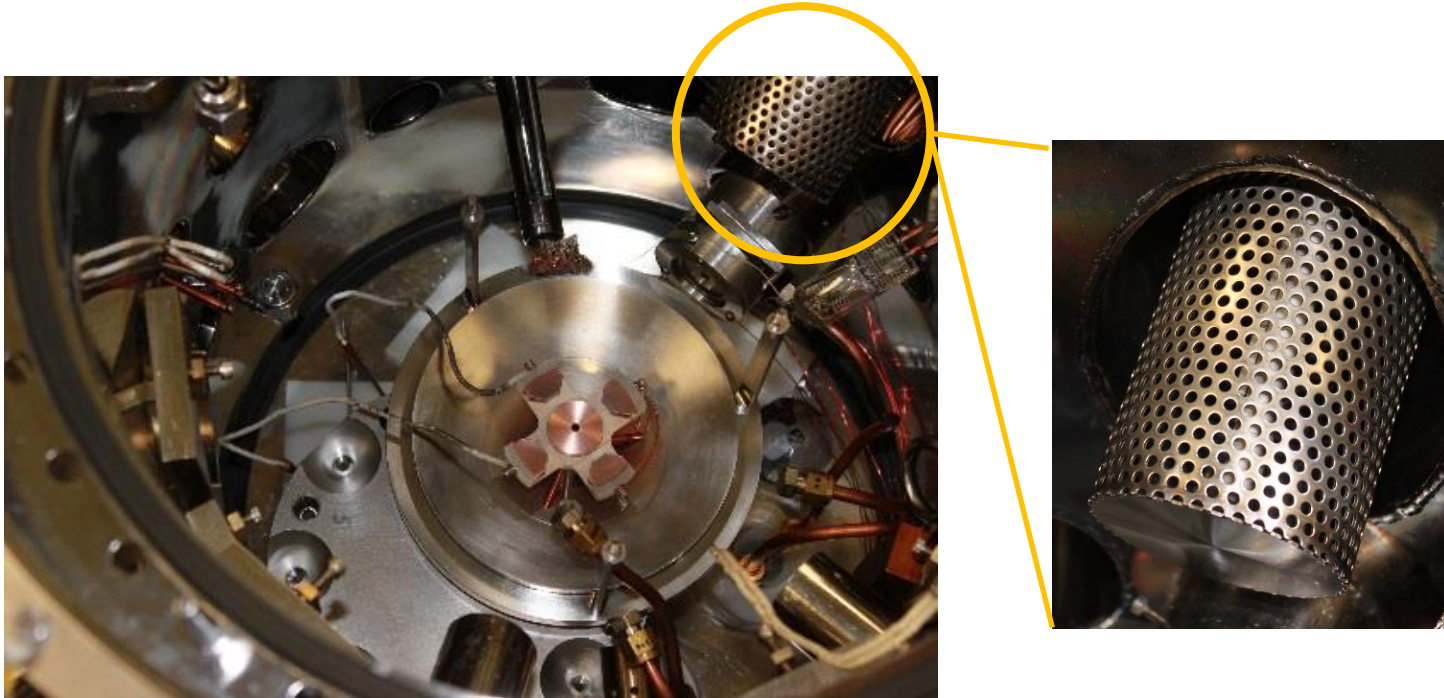


ESL Processing

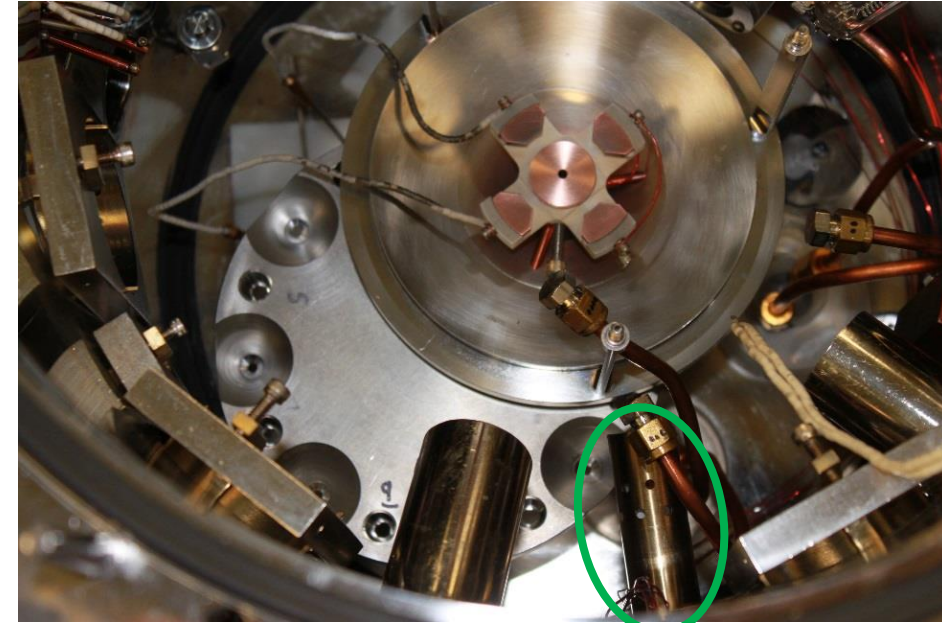
Thermal Profile at vacuum
2 mm sample (40 ± 10 mg)



Oxygen Partial Pressure Control System



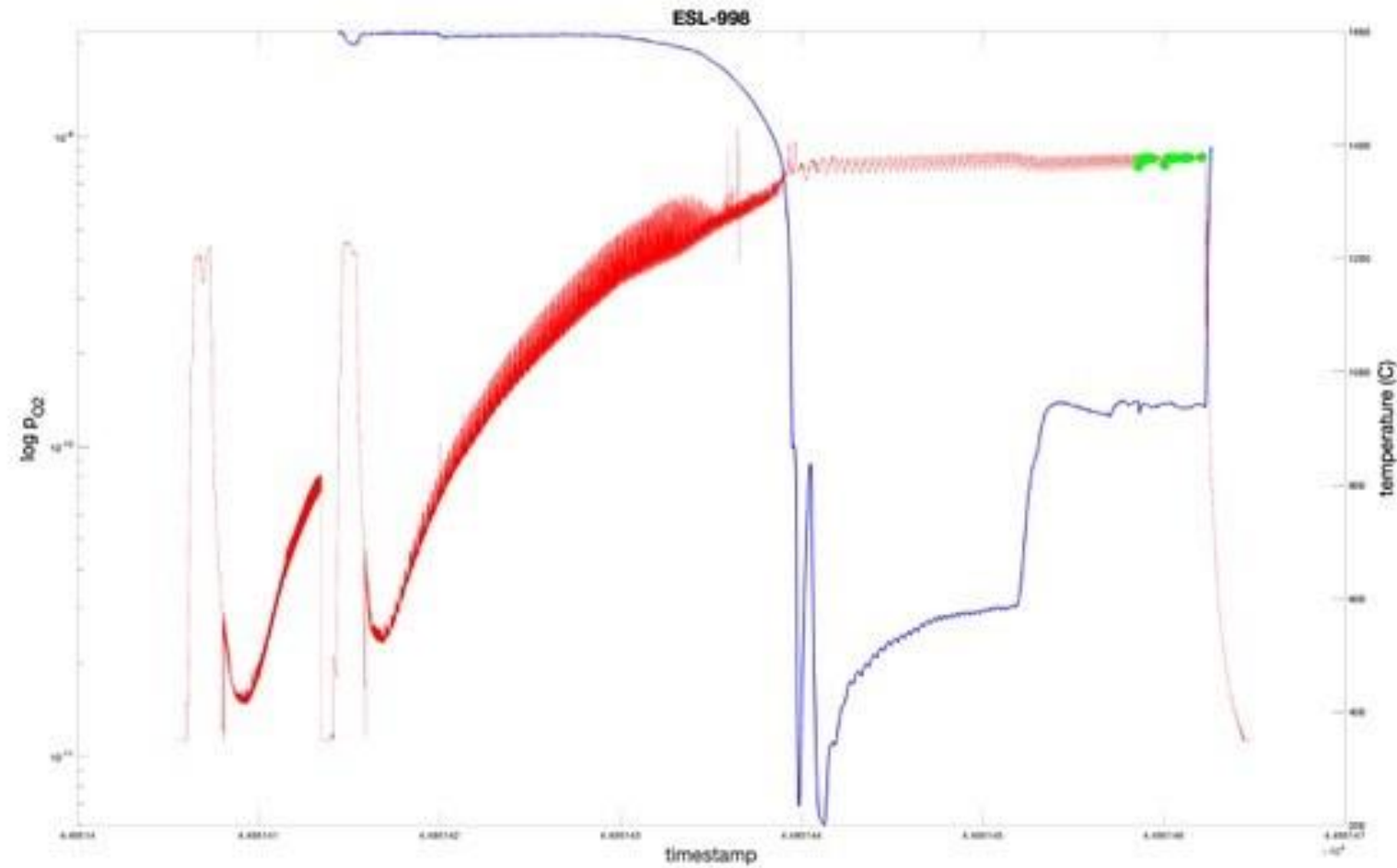
Oxygen Pump inside the levitation chamber.



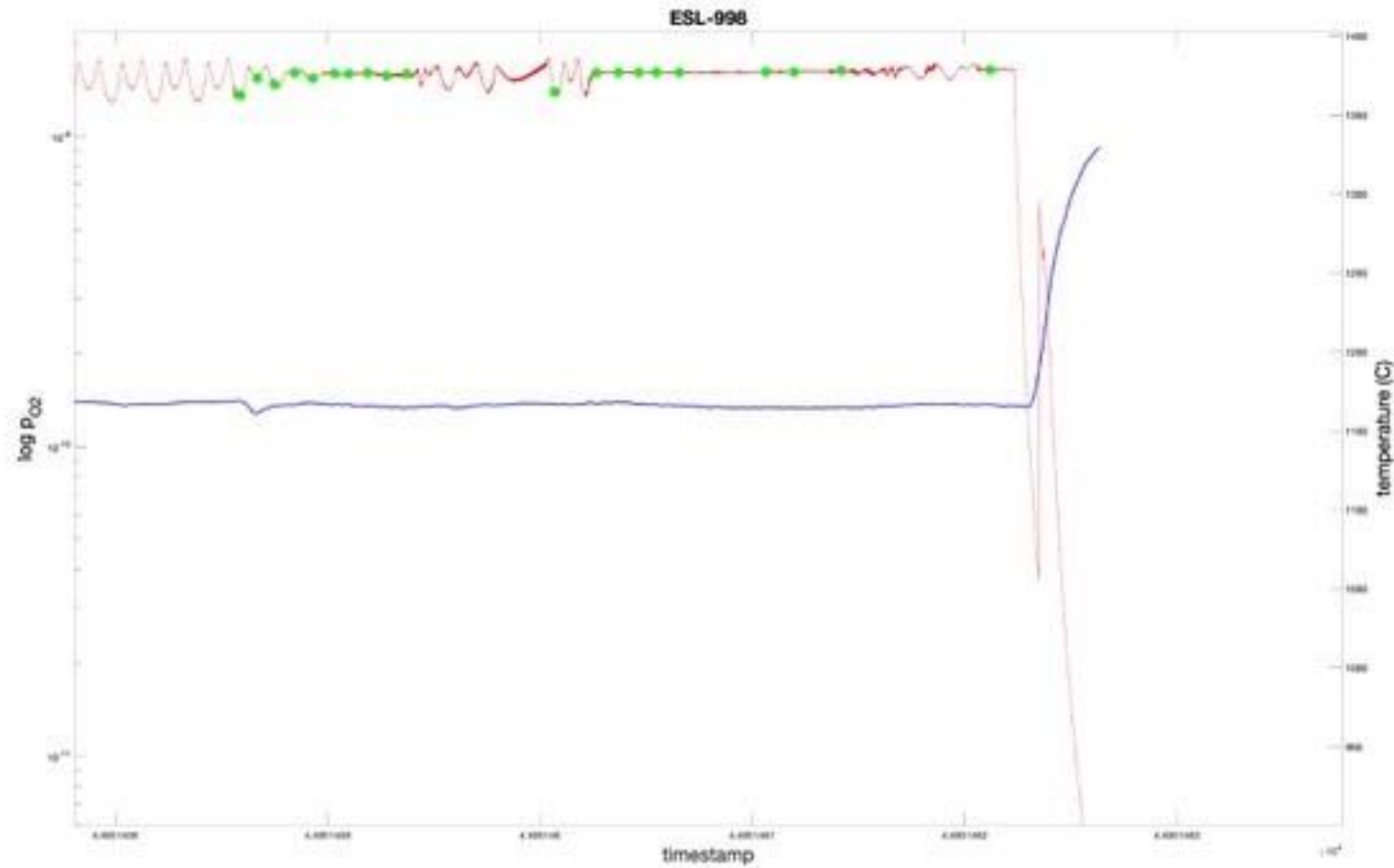
Oxygen Sensor inside the levitation chamber.

- Developed by Astrium North America
- Fabricated by Clausthal University of Technology (TU Clausthal)

Example Oxygen Control Plot



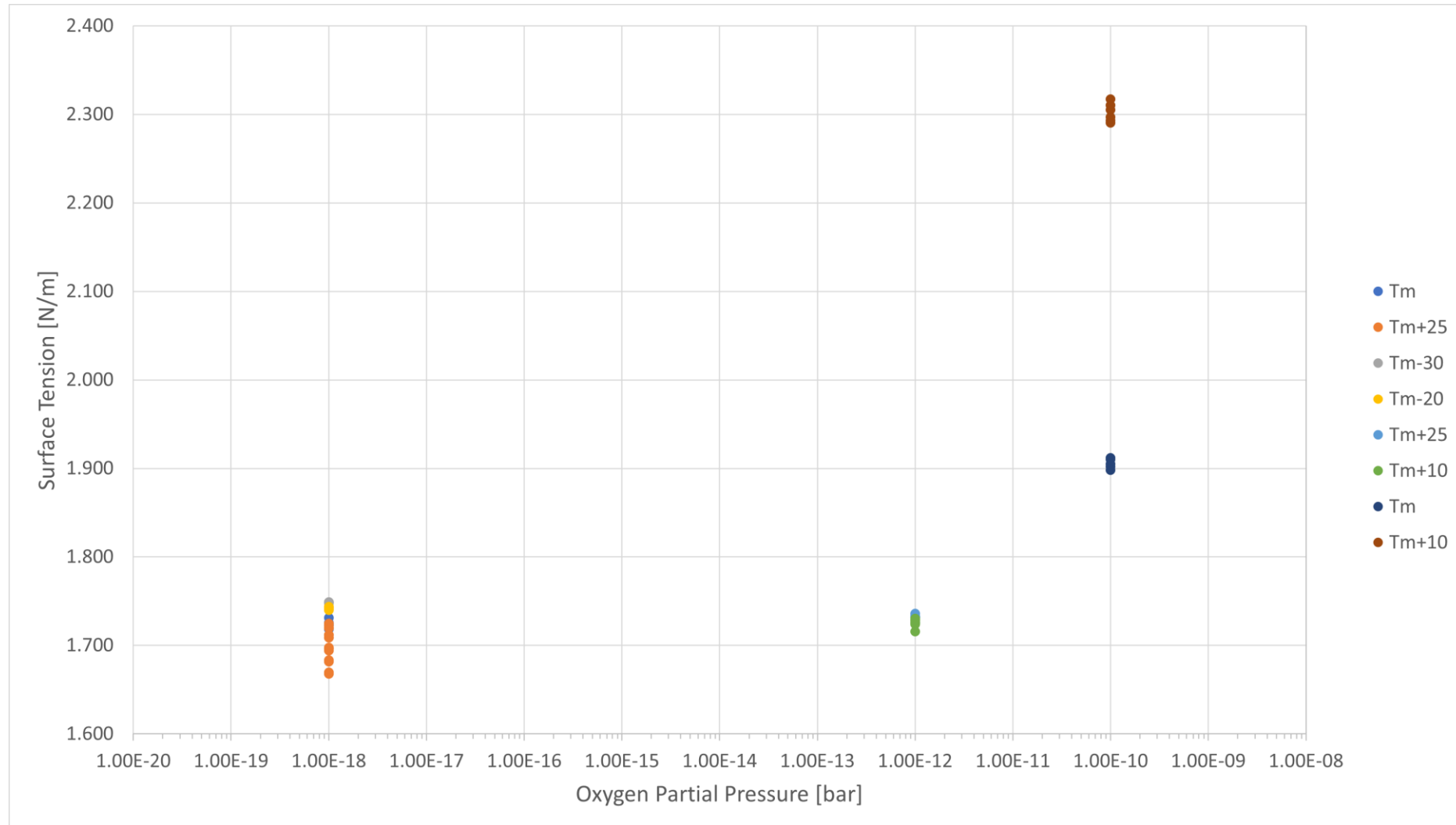
Example Oxygen Control Plot



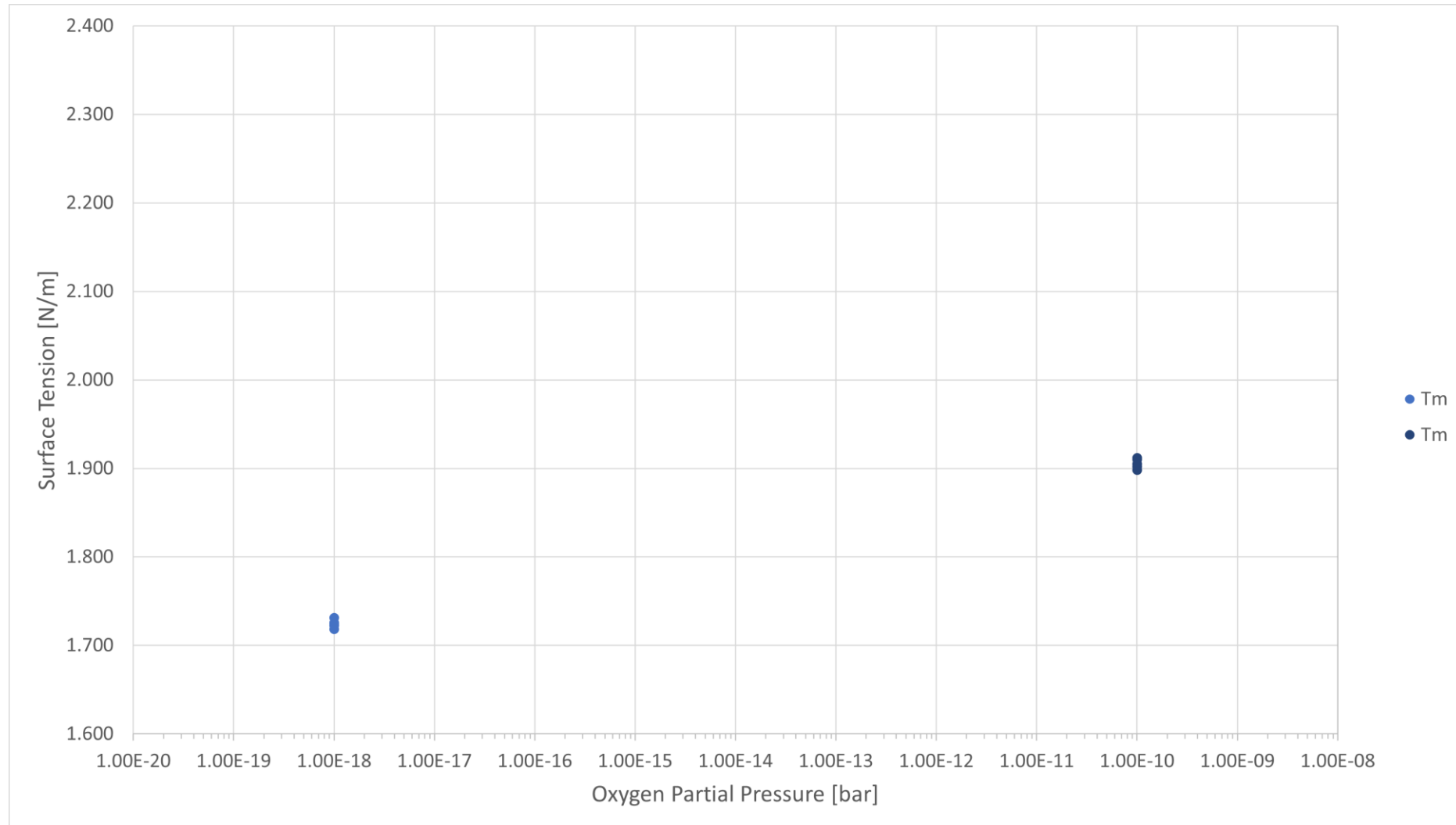
Test Matrix

- **Inconel 718**
 - Samples were made from rod stock
 - Cut into small wafers by diamond saw
 - Arc melted into spheroids
 - Samples were cleaned with ethanol
- **Sample processing only occurred after the oxygen partial pressure reached equilibrium.**
- **Melting caused the pO₂ to change, but the OPPC eventually equilibrated the pO₂**
 - Surface tension measurements were mostly taken after the OPPC equilibrated
- **Oxygen partial pressures studied**
 - 10^{-10}
 - 10^{-12}
 - 10^{-18}
- **Surface tension measurements**
 - $T_m - 30^{\circ}\text{C}$ to $T_m + 25^{\circ}\text{C}$

Results



Results



Conclusions

- **Results show a dependence on oxygen partial pressure**
 - Surface tension increases with increasing partial pressure
 - opposite expectations
- **Oxygen control plots indicate that oxygen is absorbing into the sample**

Acknowledgements

- **NASA Biological and Physical Sciences (BPS)**
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 - Trudy Allen and Glenn Fountain at MSFC
- **UMASS and WPI for analyzing the data**

Thank you.

